Meteorology.

Meteorology has for many years been, one might almost say, the only branch of physics concerned with actual happenings, and the statistical methods which have been used in the past have been too much of the kind that are applicable to a homogenous aggregate of erratic elements. Statistical meteorological studies have in most cases involved the leveling process of simple averaging, whereas the conditions would seem to require classification, classification ten thousand times more exhaustive than any hitherto made. Of course there is some interest attached to the average in meteorology because systematic differences and rhythmic changes which are extremely important are discovered in this way, but even such things would be more easily detected if the averaging process were based upon a much more exhaustive scheme of classification. In thinking of emigrating to Mesopotamia after the war, the writer has wished to know what the average weather conditions there might be for a lifetime or two, but as a resident of Boston, he is chiefly concerned with the variations of Boston's weather. Will the late frosts next spring deprive him of apples? Will winter's cold make him wish he were in Florida? And if he should be driven to Florida what weather welcome would he get there? It is certain that the most important phase of meteorology is to deal with particulars and not with averages, and its ultimate aim is weather control.

Saying very little, therefore, of the need of researches of the classical kind in meteorology, for everyone recognizes this need, let us point out what seems to be most urgently needed in the most difficult phases of the subject and we make the statement brief in the hope that it will be interpreted with the help of what we have said concerning the new point of view that is developing among physicists.

Three fairly distinct objects are to be attained in the analysis of weather observations, namely:

(*a*) The determination of systematic variations in time and place. This object has long been recognized by meteorologists.

(*b*) The elaborate classification of individual storm movements with respect to a great number of measurable or specifiable characteristics, and the establishment of statistical coefficients of correlation between the characteristics of a given type of storm on successive days so that weather predictions can be made and qualified, as they should be, by probable departures. This object has, of course, been recognized by meteorologists but we believe that classification studies should be very greatly extended.[11] Effective schemes of classification can only be developed under the stimulus of intensive study of actual weather conditions (weather maps, let us say). This sort of study might properly engage the whole time of a large staff of men, and probably the observational work and instrumental equipment of the Weather Bureau would have to be altered in response to the clearly conceived demands for new kinds of data.

(*c*) The intensive study of weather conditions should lead to a clear recognition of critical conditions in a given storm movement (conditions of static or dynamic instability) and make it possible to devise means for controlling the storm movement by the suitable expenditure of very moderate amounts of energy at the critical time and place. Anyone who has seen an old-fashioned prairie fire brought under control by carefully considered backfiring, and who recognizes the meanings of static and dynamic instability in their influence on a complex physical system like the atmosphere, will accept this idea of weather control as a legitimate conception, to say the least. Whether it can ever be actually realized, however, is another thing; but it seems well worth the attention of the meteorologist. Although every atmospheric movement may, perhaps, be properly thought of as the collapse of an unstable state, it is probable that such collapse is already well under way in the earliest stages [12] of every movement so that extremely critical states may never develop. Therefore the energy required to control a storm movement might always be considerable in amount from the human point of view, although extremely small as compared with the total energy of the storm movement itself.

[11] Some of the more recent classification studies are as follows: Bowie, E. H., & Weightman, R. H.: Types of Storms of the United States and their Average Movements, M. W. R. Suppl. 1, 1914; Types of Anticyclones of the United States and their Average Movements, M. W. R. Suppl. 4, 1917.
Henry, A. J., Bowie, E. H., Cox, H. J., & Frankenfield, H. C.: Weather Forecasting in the United States, W. B. Pub. No. 583, 1916.

[12] The discussion of simple sweeps and of steady sweeps on pages 154–155 of Franklin and MacNutt's General Physics will help to make this clear.

DYNAMIC HEATING OF AIR AS A CAUSE OF HOT VOLCANIC BLASTS.

By GEORGE N. COLE, M. E., Associate, American Society of Civil Engineers.

Probably there is no field so virgin or inviting for scientific marshaling as that part of the meteorological domain which has to do with atmospheric phenomena caused by, and following, volcanic eruption. Its ramifications reach from the vapor condensation and electrical effects of the storm to the dynamic record of the destruction of things, animate and inanimate, that fall before it. At the eruption of Mont Pelé 30,000 human beings were killed in an instant under most appalling and marvelous circumstances, yet not a single autopsy was performed and no published account can be found that assigns a sure explanation of the cause of death.

In a previous paper [1] the writer has quoted at length eminent authorities who set for themselves the question, "What causes the deaths?", and all give practically the same answer, "The hot blast, bearing sand and steam from the volcano". This is corroborated by the learned Viennese geologist, Prof. E. Suess, and by B. Koto,[2] of Japan, who refer to the "hot vapors and steam cloud of Mont Pelé."

It will not be the function of this paper to inquire into the ordinary smoke, vapor, and electrical effects of the eruption. They are probably of the usual nature of storm phenomena, greatly intensified by the magnitude of the action, which involves great differences in temperature, with unusual volumes of water and volcanic matter. Our task will be an inquiry into those blasts which, with swift and stifling stroke, rend, burst, blister, ignite, and upheave all that oppose them till their fury is dissipated by distance and their ardor cooled by mixture.

Volcanoes are not laboratories. They can neither be selected in advance with even approximate certainty, nor can safe stations for apparatus be chosen. After the experiment, physical and biological changes of enormous magnitude must be read in terms of analogy from our experience.

Just after the Martinique disaster it was related to the writer that bodies had been found apparently unharmed and untouched except for blisters and burns and that these blisters were under clothing, at times as frail as lace, that showed no trace of fire or scorch, nor were there contiguous evidences of fire. These people had

[1] Scientific American Supplement, May 25, 1918, 85: 334–336.
[2] Tokio Imp. Univ., Coll. of Sc. Jour., 38, 1916–17, art. 3. B. Koto, p. 71

been killed in some mysterious manner, just as the people of Pompeii and Herculaneum had been killed, stopped on the instant. The cause of death was unfathomed in the recent case, as in the earlier. We believe it was the adiabatic compression of the enveloping air, with its consequent rise in temperature, that stifled and killed, in almost a twinkling, the victims of Mont Pelé and Vesuvius, of Taal, and Sakura-Jima. The problem is of vital human interest.

Such heating by compression was first advanced by the writer shortly after the Martinique disaster as the explanation of the death and blisters beneath untouched lace before alluded to, but it has been the desultory work of years to assure oneself of the originality and worth of the conception and to accumulate in a small way the analogies from authentic sources and broadcast experience which would insure its acceptance.

Let us consider, first, the physiological and structural effects of the hot blasts; second, from these let us stipulate what conditions of pressure, winds, and temperatures would be necessary to produce such effects; and third, let us compare such conditions with those which occur on a smaller scale in explosions of known intensity.

The physiological, or rather pathological, effects of the hot blasts seem to be both those resulting from rise in temperature and from the rise and fall of pressure as an explosive wave passes with greater or less rapidity. Observers have reported cases of the destruction of materials varying from practical annihilation to the case of lace and fine cloths untouched, over bodies blistered and killed. Trees are cited,[3] denuded of bark, with their fiber cut and shredded as by a sand blast. This is probably the manifestation of some such action as that which pops corn or puffs rice when the pressure is removed after heating and compressing the included juices or moisture. As to heat actions on man and brute, they are reported and photographed in great quantity and variety.

Mr. George Kennan in his Tragedy of Pelée reports quite extensively, among other interesting data, the interview with one, Caparis,[4] who was a negro town character at St. Pierre incarcerated for some minor offense. For attempting to escape the day before the disaster he was put into a deep dungeon for safekeeping and punishment. He was the only being of some 30,000 in St. Pierre who survived. Some persons doubt the existence of this negro, but my friend Walter C. Harris, with Louis Siebold, both of the New York World, state that while they did not see the man—they left in an hour and a half after arrival to escape the second eruption—they were given a photograph of him, of which I have a copy; and the story of him was so circumstantially told to them by different natives as to be true beyond question, and has recently been verbally confirmed to me by Mr. Lyder, who was a member of the Barbados Government relief expedition.

This man Caparis, Mr. Kennan tells us, had been burnt so deep that blood oozed from his wounds, and yet his hair was untouched, as was also the shirt covering the burns on his back. Caparis told him that he heard no explosion and smelled no odor of sulphur. He was in an underground cell with a door grated in the upper part and the air and dust came through and burned him. He heard no noise, saw no fire, and smelled nothing except what he thought was his own body burning. The water in his cell did not get hot, or at least it was not hot when he first took a drink, after the catastrophe.

[3] Dean C. Worcester, Nat. Geogr. Mag., Apr., 1912, Taal Volcano, p. 345.
[4] Tragedy of Pelée, George Kennan, 1902, p. 74, and following.

In the Philosophical Transactions of the Royal Society of London (vol. 200 A, 1903) Drs. T. Anderson and J. S. Fleet in their article "On the eruptions of the Soufrière and on a visit to Montagne Pelée in 1902," pages 353–553 and plates, give much valuable information and data. This supports the theory of the dynamic heat of compression, although it did not occur to them, and they cling to the older theory of black cloud, hot sand, and steam.

Their observations and statement as to the black cloud are the most minute we find, and are quite interesting. The cause of this black cloud, also alluded to by others, is not entirely clear to the writer, but may probably result from the formation of the enormous quantities of dust made by the solidification or condensation of the liquid and gaseous material which exploded violently on the release of pressure when ejected from the crater. It may also be that the high density of the atmosphere as it comes under compression would so vary its refraction, especially with its undoubtedly disturbed surface, as to cause it to become nontransparent and dark. Another factor in the production of the black cloud must be the dust blown up from the surface by the tremendous wind.

Their report notes in one instance sufficient heat in ashes to scorch a negro's skin but not for two hatfuls of the same hot ashes to singe his hair. Their records of pages 396–398 strongly illustrate experiences on the outskirts of the danger zone of an eruption, especially their reference (p. 398) to the Fancy estate: "Those who escaped were badly burned mostly on the hands, the feet, and the face, but others also on parts protected by clothes, though their clothing was *not scorched* or *ignited*. The dust in the cloud was not red hot and consequently did not set anything on fire, the burns being apparently due to *steam and other gases*." The italics are our own.

The other extreme of burning observed after such volcanic blasts is that in which torsos of bodies burned beyond recognition with the cement of sand on them after burning are found in situations where all wood and inflammable material was likewise ignited and consumed. One case of disrupted bowels is cited in the Century Magazine for September, 1902, which may have been the result of flatulence and a sudden reduction of pressure after the pressure blast.

Destruction of material objects shows the action of a tremendous blast from the direction of the crater. Ground plans have been plotted for numerous eruptions and they show irregular, but, in a measure, concentric fields. Photographs taken of volcanically destroyed localities also show these nicely graded zones of destruction from that of utter havoc nearer the crater, to those exterior zones where whole villages are still partly standing with walls destroyed across the line of march of the pressure front, but with walls which coincided with the direction of approach of the pressure preserved. Dr. E. O. Hovey in his remarkable photographs of St. Pierre, Martinique (Bull. Amer. Museum of Natural Hist., Vol. XVI, plates), states in description of Plate XLV: "Ruins of St. Pierre from the south—the north and south walls have been injured by the eruption less than the east and west walls." It will be noted that the crater was situated to the north of these walls. He also exhibits photographs showing trees all thrown down in a direction away from the crater.

Observations leave no doubt that there is a tremendous hot blast with a great wave of pressure emanating from the crater generating a terrific compression with its attendant high adiabatic temperature since there is little time for dissipation of this heat. This compression of gases at the crater is accomplished by three actions:

First. The magma of the volcano approaching the outlet as a liquid, due possibly to some modification of a deep internal regelation, under heavy pressure and with intense heat is probably in the condition of the water in a boiler exploding under such intense pressure and its attendant temperature that the heat contained in the water causes the whole of the water to flash into vapor. By analogy we may possibly conceive of the ejecta of the volcano being entirely vaporized on its release to external pressure, later, on condensation, to become the sand and grit that covers the landscape. The mechanical extrusion of this vapor in itself makes the first wedge to crush the air into compression before it.

Second. The heat of this extruded matter, even after the expansion of emission, in its action on the surrounding air will cause it to expand, as the air in a back draft at a building fire, so that the expansion of the air itself will cause the air retaining it to be thrown into compression.

Third. Some of the extruded gases may be inflammable, and by their conflagration cause further heat and expansion, which will bring to bear further action compressing the outside counteracting atmosphere.

These three causes combine to give a drive and pressure to the retaining atmosphere beyond anything obtaining in other atmospheric disturbances both as to velocity and temperature.

This gives rise to destruction as complete in the outer zones of action as if done by a tornado. The velocity of the wind near the crater is incalculable, but must be of the order of more than 100 meters per second. The temperature of the gases, likewise incalculable at the crater, must range from 500° or 1,000° C., or beyond, to 200° or 300° C., where things are charred, and to over 60° C., where people were burned without their clothing having been affected. Furthermore, such temperatures must have been maintained for a time sufficient for the surfaces to get warmed to a temperature sufficient to produce the observed burns. It is a matter of common experience that only a second or two is enough for hot air to produce a burn and less than a second for steam to scald, while it may take some considerable time for a third-degree burn or worse.

Macleod, in his "Burns and their treatment," of the Oxford War Primers, gives us the discussion from which the following notes are taken: A burn is caused by a dry heat of about 140° F. (60° C.) and above; a scald by 125° F. (52° C.) and over. The degree of severity is dependent on—temperature, area exposed, and duration of exposure. The area affected is more serious than the depth of the burn. Six degrees of burns are recognized: (1) From a temperature of 140° F., redness, slight œdema (effusion of serous fluid), smarting, and tenderness; (2) from 160°–210° F., marked blisters, protoplasm coagulated; (3) above 210° F., hard crust or scab is formed; (4) longer exposure to high temperatures, disintegration of skin tissues; (5) still longer cooking, with disintegration of muscles; (6) higher temperatures, carbonization. Burns involving more than one-third of the surface of the body are serious, if not fatal, and those involving one-half are almost invariably fatal. The more intense degrees of severity of burns would naturally take some time for their accomplishment and might be a measure of the duration as well as intensity of the heat involved. Mucous membranes are also seriously affected by the inhalation of the hot vapors. As the temperatures increase, hair and eyelids, ears and nostrils, will be affected. Thus from the observed effects we have a rough basis for judging the temperatures which occurred.

To estimate the increase of pressure in the compressional wave, we can use (1) the strength of the blast produced; or (2) we can estimate how much increase or decrease in pressure would produce the collapse or explosion of buildings, trees or people; or (3) if we assume the high temperature to be wholly a result of adiabatic compression, we can use the estimated temperatures as a rough basis. Let us consider each. In an explosive wave it is probable that the pressure front in the destructive zone moves at a velocity greater than that of sound, or at a speed perhaps of 400 meters or more per second, varying with the actuating force, and having a destructive force inversely proportional to the distance. Thus the wind speed, no matter what the gradient, could attain a velocity of 400 meters per second were it not for viscosity and friction. The explosive effect of tornadoes seems small compared with that of the passing explosive wave with its hot blast, until its force is about dissipated. Barograph traces made at a slight distance from tornadoes have shown pressure reductions as great as 10 per cent, and it is presumed that in the tornado itself the reduction may be much greater. A release in pressure so great as this is capable of exploding buildings and probably also is able to explode bark on trees and to kill people, although it has none of the marked heat effects of the air compression. An explosive wave, however, is a study of much higher compression and its reduced pressures follow necessarily from the fact that there is the preceding compressional wave by virtue of the air from behind being thrust into that in front. The compressions we are considering are those involving some little length of time and magnitude of expression, before the action has so expanded as to be a mere wave motion. Our thesis covers the part of the field of action outside of total destruction, where heat effects are of such modified intensity and duration as to leave observable effects on material and living objects.

On man and brute in this zone the sudden rise in pressure, aside from its heat effects, must be indescribably worse on the eardrums than going through an air lock in caisson work. Lung and heart action must be stifled since the ordinary maximum difference between the inside and outside of the lung wall, on strong stopped expiration, is from 60 to 100 mm. of mercury, or about one-tenth of an atmosphere. Then, depending on the length of application, in case the subject can breathe at all, is the absorption of air into the blood, with the consequent liability to "bends" on release. On the relaxation of this pressure, with its consequent relative vacuum, all the contained air in structure of plant or body becomes a bursting charge if not sufficiently secured. In animals, even if there is no explosive effect, the nitrogen will form bubbles in the blood if the pressure has been sufficiently prolonged, and in this way clog the circulation and cause death.

The pressure necessary to cause the different degrees of heat, if we assume (as is reasonable with such sudden compression) that the heating is adiabatic, or without loss of heat during compression, may be determined from the well-known gas formulas.

The relation between temperature, pressure, and volume of air at the beginning and ending of adiabatic compression (or expansion) can be deduced from Charles' and Boyles' Law as follows: [5]

According to these laws

$$P_1V_1 = PV\frac{T_1}{T} \text{ ---------------- } (1)$$

whence

$$\frac{P_1}{P} = \frac{VT_1}{V_1T} \text{ ---------------- } (2)$$

For adiabatic compression

$$\frac{P}{P_1} = \left(\frac{V_1}{V}\right)^n \text{ ---------------- } (3)$$

or

$$\frac{P_1}{P} = \left(\frac{V}{V_1}\right) \text{ ---------------- } (4)$$

In which n is the exponent of adiabatic compression, 1.406, and is the ratio of the specific heats of air at constant pressure and constant volume.

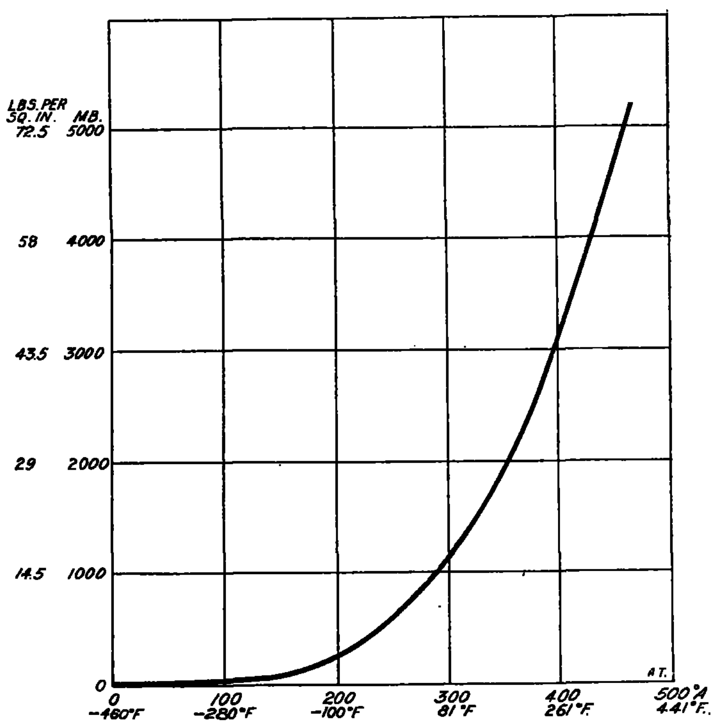

FIG. 1.—Temperature changes under adiabatic compression. Adapted from Thurston's tables. Correction: Change 81° F., 261° F., and 441° F. to 80° F., 260° F., and 440° F.

Combining (2) and (4)

$$\left(\frac{V}{V_1}\right)^n = \frac{VT_1}{V_1T}$$

whence

$$\left(\frac{V}{V_1}\right)^{n-1} = \frac{T_1}{T} \text{ ---------------- } (5)$$

and

$$\frac{V}{V_1} = \left(\frac{T_1}{T}\right)^{\frac{1}{n-1}}$$

or

$$\frac{V_1}{V} = \left(\frac{T}{T_1}\right)^{\frac{1}{n-1}} \text{ ---------------- } (6)$$

[5] From Simons', Compressed Air, p. 26.

from equation (3)

$$\frac{V_1}{V} = \left(\frac{P}{P_1}\right)^{\frac{1}{n}} \text{ ---------------- } (7)$$

or

$$\frac{V}{V_1} = \left(\frac{P_1}{P}\right)^{\frac{1}{n}}$$

whence

$$\left(\frac{V}{V_1}\right)^{n-1} = \left(\frac{P_1}{P}\right)^{\frac{n-1}{n}}$$

and combining with equation (5)

$$\frac{T_1}{T} = \left(\frac{P_1}{P}\right)^{\frac{n-1}{n}} = \left(\frac{V}{V_1}\right)^{n-1}$$

Based on these equations, a general summary of the relations between pressure and temperature in adiabatic pressure changes is shown in Table 1 and Figure 1.

TABLE 1.—*Temperatures in adiabatic compression or expansion.*

[Adapted from tables by R. H. Thurston, 1874.]

In these tables the temperatures are slightly inaccurate, absolute zero being given as −274° C. and −461.2° F., instead of −273.1° C. and −459.6° F.

Pressure.			Temperature.		
Pounds per square inch.		Millibars.	°F.	°C.	°A.
Absolute.	Gauge.				
5	−10	345	−80	−62	212
10	− 5	690	5	−15	259
15	0	1,035	63	17	291
20	5	1,380	109	43	317
25	10	1,725	147	65	339
30	15	2,070	180	82	356
40	25	2,760	236	114	387
50	35	3,450	282	139	413
75	60	5,175	375	190	464
100	85	6,500	447	231	505
500	485	32,500	988	531	805
1,000	985	65,000	1,258	681	955

This table shows at what relatively low pressures, added to the atmospheric pressure, severe temperatures are reached. To make this more closely applicable to the conditions which probably prevailed at St. Pierre, let us assume that the original temperature was about 80° F. and the original pressure somewhat below the mean for sea-level, say, 1,000 millibars (equivalent to the pressure shown by a barometer reading, 750.1 mm. or 29.53 inches).

Table 2 shows what pressures would be necessary to produce the temperatures required for burns of the first degree, of the second and third degrees, and of the sixth.

TABLE 2.—*Temperatures in adiabatic compression or expansion.*

[Initial temperature, 27° C.; pressure, 1,000 mb.]

Pressure.			Temperature.		
Pounds per square inch.		Millibars.	° F.	° C.	° A.
Absolute.	Gauge.				
14.5	−0.5	1,000	81	27	300
21	6	1,430	140	60	333
31	26	2,120	212	100	373
70	55	4,800	392	200	473

In other words, if the observed burns were due to temperatures produced by the heat from adiabatic compression, there must have been a pressure of about five atmospheres for the charring, a pressure of over two atmospheres for the severe burns, and a pressure of at least one and one-half atmospheres where there were superficial burns, provided that the pressures stated lasted for something like a second.

There are many examples of this adiabatic compression of air with its resulting heat, e. g., the heating of the old bicycle pump in the hand when in use is probably the most intimate; the fire-cylinder experiment of the physical laboratory where the piston of a closed cylinder is pushed down so far and so quickly that a bit of tinder in the compressed-air chamber bursts into flames; the Diesel motor which is actuated by the explosion of oil ignited upon being sprayed into air compressed adiabatically to a very high temperature. Each detonation of a high-explosive shell has about it the various zones of its own hot gases and the counteracting compressed hot air of a miniature eruption. So that with these and other examples it is a heat of which we have experienced various analogies and in its lighter stages is readily comprehensible. The heavier manifestations of this heat are more difficult to fathom. Mixed as they are with the equally terrific results of air motion there is good reason for there having been no previous differentiation of their coincident effects.

The observed phenomena, then, show that the hot volcanic blast is characterized by a wind velocity exceeding 100 meters per second, by temperatures from above 200° C. down to 60° C. within a zone of several miles, and by a pressure wave which probably ranges from a pressure of one and one-half atmospheres to one-half an atmosphere, and which may have a pressure of more than five atmospheres.

The cause of such a blast is obviously a tremendous explosion, however undeterminate, exerted upward, but conforming, in a measure, to the effective axis of the outlet, the whole process being liable to distortion, due to the barricading of crater walls and mushrooming, due to diverse air strata encountered. This explosion throws solid and liquid lava and hot gases in all directions. It sends out at a tremendous velocity a great compressional wave with an approximately spherical front. Such explosions can throw rocks more than 30 miles, and the liquid lava makes almost unbelievable quantities of volcanic dust. The hot gases are forced to not great distances. The explosive surge has an unknown change of pressure. It is obvious, however, that an explosion of such intensity as to make appreciable pressure waves encircle the earth, as at the time of the Krakatoa eruption, must produce a tremendous initial wave of compression and expansion, the initial compression being of some duration, depending on the suddenness and persistence of the source and the following rarefaction conforming to it in magnitude.

The amount of pressure will probably never be determined. In the great Krakatoa explosion an island disappeared and a boulder was hurled over 30 miles, ascending 30 miles in its flight and surpassing our usual 16-inch gun to an incalculable degree. Since the missile was fired by a flare or explosion rather than within a rifled barrel, the intensity must have been incalculable times that of a great gun.

Let us turn to the causes for the various grades of destruction. Those near the crater are due to the explosive action and heat of the gases as they emerge. These gases hurl and burst the material of the mountain so as to obliterate or cover it in an indescribable manner. But these gases and missiles do not of themselves necessarily range far in their travels. The wide damage seems to be done by the action of the surrounding atmosphere, through which moves the compressional action produced by the explosion.

Quoting from the second volume of Marshall's Explosives (p. 621), recently issued,[7] we find that—

> Experiments have been carried out at various times and places to ascertain the distances at which explosives will produce a specific effect according to the quantity of explosive used. In the French experiments different quantities of the various explosives were exploded in the open, and at various distances a number of little screens were erected, so arranged that the same degree of force would cause each of them to fall back. It was thus possible to ascertain the distances at which the same effects were produced. The most simple theory would lead one to expect that the distance would be proportional to the square root of the weight of the charge. These experiments, which were carried out with quantities of 0.1 to 100 kg. of melinite, 150 kg. of chedite, and 300 kg. of gunpowder were in agreement with this theory. They were confirmed by trial in which small huts with glass windows were exposed to the effects of the explosives at various distances.
>
> This rule is expressed by the equation $d=K\sqrt{c}$, where d is the distance, c is the weight of the explosive, and K a constant depending on the nature of the explosive and the sort of damage considered.
>
> For high explosives causing the breaking of window panes and slightly injuring the frames and wooden walls K=10, about, the distance being measured in meters and the charges in kilograms. L'Heure also determined the velocity with which the impulse of explosives is transmitted through the air. Near the seat of the explosion the velocity is much greater than the normal velocity of sound, but it falls off rapidly and at about the distance at which window panes are no longer broken the velocity is the same as that of sound. The more brisant [sharper] the explosion the greater is the initial velocity of the impulse. Increase of the quantity of the explosive does not seem to increase the initial velocity but it causes the rate of diminution to be less.
>
> For small quantities of explosive the distances of equal effect are nearly proportional to the cube root of the weight of the explosive and for very large quantities the variation of the distance is more nearly proportional to the increase of the weight.
>
> The gases formed in powder explosions are projected to comparatively small distances. When 7,000 pounds of gunpowder exploded at Faversham, England, and the conditions were peculiarly favorable to lateral projection, the scorching effect did not extend over 50 yards, whereas serious structural damage was done at 283 yards and windows were broken at a mile.

Could not some computations be made to show the amounts of pressure change accompanying explosions of varying intensities, and to show the damping effects of the atmosphere on such compression waves? From such it might be possible to compute the initial intensity of any explosion from the distance to which the destructive effect reached.

In the volcanic eruption the question is, Do the hot crater gases actually sweep down the mountain as a withering blast effective for miles around? If not, the hot blast must be the result of compression on the front of the explosive wave. The fact of pressure disruption of trees, buildings, and even of men, and the reported compression of the air in Caparis's dungeon, and the burns under clothing indicate a pressure wave of sufficient magnitude to produce the observed heating and wind effects. A blast of hot gas would, however, also be accompanied by a pressure wave, though not so intense as the explosion wave. Since, however, in many devastated locations no gases were smelt so far as known, it seems reasonable to explain the hot blast as the result of the passage of a tremendous compressional wave traveling at a speed exceeding the velocity of sound (which is about 335 meters per second). Such a wave would kill by compression and rarefaction as well as by burning. The duration of the high pressure at any

[7] Explosives: Arthur Marshall, P. Blackiston's Son & Co., 1917. 2 vols.

spot may be as much as a half or even a whole second or longer, depending, upon the persistence of the source.

To prove this point, further observations of the intensity and duration of the explosive wave are necessary. The destructive forces in play make observations impossible. Instruments set to register and yet resist demolition, in case the time and place can be foretold are the best that can be hoped for. These instruments should be designed to register pressure, duration, heat, and if possible gather some of the atmosphere. Much ingenuity will be required in the design and making so that they will be indestructible, self-contained and yet give access for calibration and for reading and determination. As an initial suggestion, and for want of better, it is believed that pressure can best be determined by an aneroid cell of heavy metal with copper points within it, attached to either plate, arranged for indentation. Possibly the cell can be screwed together by threads in its cylindrical part, thus allowing proper setting, testing, and reading. The indenting plug might be widely conical with a spiral ridge. There could be used also containers set with a spring plug that would allow entrance of air or gas at given pressures but stopped for egress. These if exhausted when set would keep air samples and might retain their maximum pressure.

Duration of pressure might be obtained by a timing mechanism within a strong capsule which would be released for motion while the pressure is acting on the plates of the container.

Temperatures and heat would probably be best registered by their effects on exposed objects since the action may be too speedy for other registration. Thermopiles might be arranged to register their throw or to indent their difference of expansion.

Records, after all, will generally be obtained by visits, as soon as may be, to fields of action, and by the preservation or the measurements and description or photographs of specimens, also by attempting through physical and chemical processes to duplicate observed changes. A special set of apparatus that will register results in the midst of great pressure disturbance will need to be designed, in case it is thought it can be advantageously placed.

How can safety be achieved? With a wave traveling at such a termendous speed there is little chance to seek safety; but presuming it is possible, all of three things are necessary in a "volcano cellar"—stability, heat insulation, and pressure insulation. If one is inside the danger zone none of the above can be overlooked. On the outskirts of devastation, cellars, dungeons, caves, wells, or cisterns may help some, but it will all be a matter of the severity of the pressure at that particular place. If the pressure comes on it will heat the air of a cavern a hundred feet underground. For protection is simply a case of having heat absorbed by surrounding objects or by sprayed water faster than it can be generated by the compression.

A form of protection could be secured by the firm placement of a steel chamber, such as is used about caisson contracts for the treatment of those taken with caisson disease or bends. Such an air lock securely placed, heat insulated, and with air-tight doors, would be a safe refuge, provided the strain on it was not too great in any one of the three essentials. Crusher gages such as are used in rifles could be operated in its shell.

No matter what prepared protection there might be, a previous, thorough wetting of the body might be a protection against burning from air in case it is hot only about a second. In some therapeutic treatments, the body covered with wet clothes is exposed to temperatures up to 200° C. If there are poisonous gases there would be little chance for escape without a gas mask as well.

The whole matter is in a formative stage. That heat of compression is the large fatal factor to man exposed to eruptive volcanoes seems most probable, for the explosions are probably great enough to produce a pressure wave capable of heating the air to 60° C. or more for miles from the source. That this compression ignited buildings and ships, crushed in the hatches of the steamship *Roraima*,[8] denuded trees and shredded their pulp, is almost as evident. Furthermore, nicely graded effects could not have been accomplished by the ravage of hot or flaming crater gases. What can be shown by close and immediate inspection will develop. Heaven grant a long wait unless it be another Katmai without casualty.

DISCUSSION.

Theoretically, temperatures exceeding 200° C. may accompany an explosive wave of volcanic intensity. The absolute temperature of a gas varies as the total kinetic energy of the gas, i. e., as mv^2 in which m is the total mass of the molecules, and v is their average velocity. This kinetic energy can be raised by increasing the mass in a given volume without changing the velocity or by increasing the velocity by adding heat or moving the gas forward at a velocity exceeding the average molecular velocity.

According to Watson's physics,* page 171, the average molecular velocities of a few gases at 0° C. are as follows:

	Meters per second.
Hydrogen	1,859
Nitrogen	492
Oxygen	465
Carbon dioxide	396

Since air is approximately four-fifths nitrogen and one-fifth oxygen, the weighted molecular velocity at 0° C. is about 485 m./s., or at 27° C. (300° A., 80° F.) about 510 m./s.

Suppose, as seems possible, an explosion actuating the air for one second pushes the immediately surrounding air forward at a velocity of 510 m./s. If the next zone of air did not move while this air in motion was driven into it, there would be at the end of one second a zone of air 510 meters thick in which the kinetic energy has been doubled because the mass of air in that zone has been doubled, the average molecular velocity remaining the same. (Relative to a stationary object the kinetic energy of a passing blast would be still greater.) The absolute temperature would, therefore, be doubled, i. e., 600° A. Such a temperature obviously would not be reached, for the air into which the explosive surge was driving would give way to some extent. If half of it got out of the way, the temperature would be 450° A., and if even 85 per cent were driven forward the temperature would still rise high enough to burn people.—*C. F. B.*

[8] Chief Engineer Scott, Eruption of Mount Pelée, Cosmopolitan, July, 1902, p. 250.
* W. Watson, A Textbook of Physics, London, 1900.